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Experience with Reinforced Plastic Primary Aircraft Structures

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IN 1958, Piper Aircraft's Vero Beach Development Center was assigned Project PA-29. The purpose of this project was to explore the possibility of building an airplane using materials and processes that might replace aluminum alloy. Almost from the start, the endeavor was principally in the field of fiberglas reinforced plastics, and emphasis was put on comparative cost.

PRELIMINARY RESEARCH

The first phase of the work was exploratory. We wanted to know how much of a light airplane could be fabricated from plastic materials. Would available resins and reinforcing materials be satisfactory for aircraft structures? How could we build plastic parts so that they would serve as well as aluminum?

During this first part of the project every avenue of information and experience available to us was explored. Many trips were made throughout the country. We visited college hangars, plastics laboratories, manufacturing plants, plastic boat companies, government agencies, and a list of authorities in the related fields with whom we conferred would fill the remainder of this paper. It is hoped that our gratitude for this early information will be expressed in the sharing of this paper.

From the beginning, it appeared that many available resins and reinforcing materials possessed physical integrity equal to the requirements for light aircraft. These materials were moderately priced and were available.

Our first look at honeycomb as a low density core material was not gratifying. Aluminum was too expensive and would pose bonding problems; fiberglas honeycomb was too expensive, and paper honeycomb would soak up water. All these materials required several process steps before bonding to their faces would be effective. Honeycomb was put aside pending development experience.

CONSTRUCTION TECHNIQUES

Construction techniques are as broad as the imagination. We eyed a single monolithic structure as optimum. Joints, fittings, repetitive operations on components, assembly time, and other factors could be reduced or eliminated. The monolithic airplane would be lighter, stronger, cheaper to build.

In spite of these advantages a number of recent developments, such as a failproof glue joint, the increasing importance of in-process quality control, and the decision to use heat for positive curing as well as to extend lay-up time, prompted us to switch to a several piece assembly.

Wings - The final design adopted was centered around a one piece wing, tip to tip, with the fuselage resting on it (Fig. 1). This would eliminate the weight and complexity of high load bearing joints and thereby reduce the number of parts. Where the wing enters the fuselage, it changed its character and became the passenger seat.

The surface controls and most of the electrical system were installed in the wing. As a matter of fact the flaps and ailerons as well as main landing gear and brakes were installed and completely rigged before the fuselage was attached to the wing. Assembly was greatly speeded up by

ABSTRACT

Piper Aircraft's Development Center at Vero Beach, Florida, has combined a background of aircraft experience with a background of experience in fiberglas reinforced plastics in a venture that has yielded the first all fiberglas airplane. The past four years of experience with reinforced plastic primary aircraft structures have been beset with many interesting experiences which bridged the gap between exploratory planning and an aircraft that flew on April 30, 1962. Substantial progress has been made in the fields of plastic molding equipment, processes, and fiberglas aircraft design.

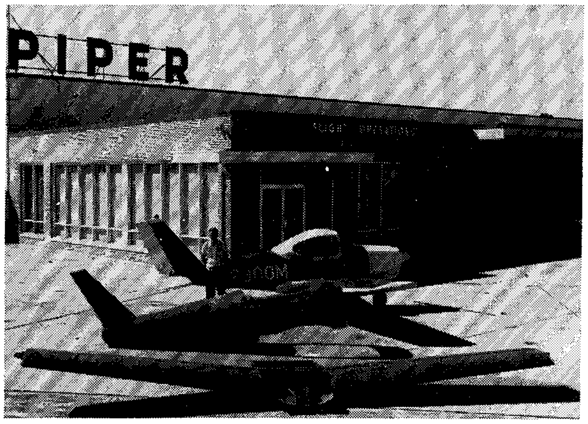

Fig. 1 - PA-129 components and airplane

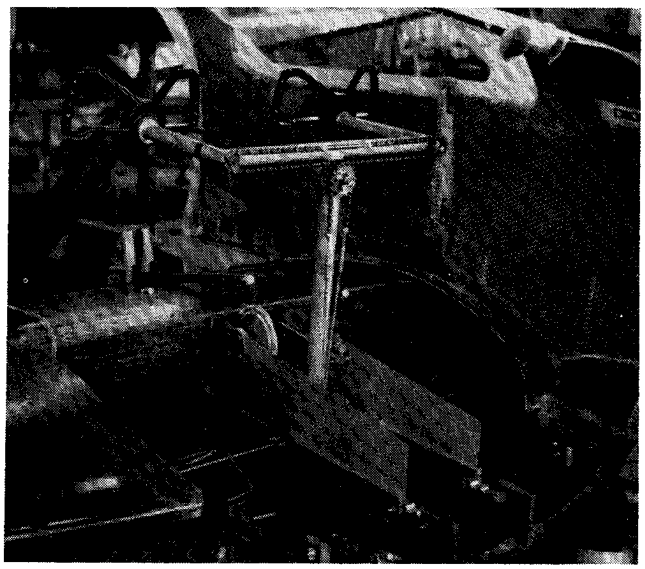

Fig. 2 - Cockpit installations in wing

having all these components out in the open where they could be worked on easily (Fig. 2).

The basic wing structure was composed of the upper and lower skins running tip to tip. The skins carried the bending and torsion loads while the spar acted as a shear web and divided the buckling panels in half (Fig. 3). The inboard section of the spar structure performed other functions such as supplying the landing gear attachment. Inserts imbedded in the lower skin picked up aileron hinge brackets, jack pads, tie down fittings, and similar accessories.

Fuselage - The fuselage was built in two halves with an integral fin. The attachments for the stabilator, wing, turnover bar, instrument panel, and engine mount fittings were molded into each half at the time of lay-up (Fig. 1). On this airplane the fuselage is a simpler assembly than the wing, since there are fewer installations in it. Again, the fuel tank and instrument panel may be installed in the inverted fuselage before it is assembled to the wing, thus simplifying these installations.

These structures were to be made completely of fiberglas, with the exception of small steel bearing plates inserted at

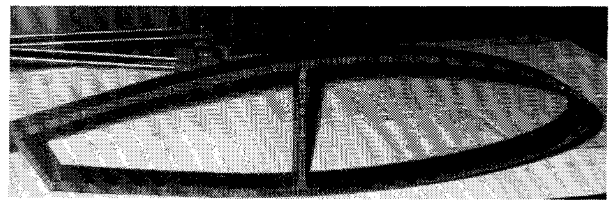

Fig. 3 - Cutaway section of outer wing

Fig. 4 - Wing skins and mold

bolted joints. It is not practical to mix structures; for instance, by using an aluminum spar in a fiberglas wing. The differences in thermal expansion, modulus of elasticity, and strain to failure will doom such an attempt from the start.

In order to reinforce our exploratory opinions, our plastic laboratory prepared and tested many physical specimens, and the numbers from these tests were compiled. This bank of information was used for design of the various areas of our hypothetical airplane. Where data were missing or special treatment appeared necessary, development jobs were initiated. This laboratory work put us in a position to have a serious go at the preliminary design of both the molds and the airplane.

Molds - In all stages of the project, plastic molds had to be developed and build before parts could be molded or tested. Glue lines of the various parts to a great extent controlled the size and shape of the part as well as the mold. The molds would be somewhat larger than the plan view of the parts. (The wing mold would measure about 27 ft long; Fig. 4.)

The molds became complex as we summed up the criteria of our process. Fit between the various large parts required close tolerances. Heat curing of parts was needed for positive cure, better quality control, and longer lay-up time than was possible with room temperature resin systems. Lightweight molds helped heat transfer, floor space limitation, and production process requirements. Pressure tight integrity was also a process requirement.

A logical approach to this problem was to select a full size 30 in. section of the outer wing panel, and with the above criteria in mind, we started to build a mold.

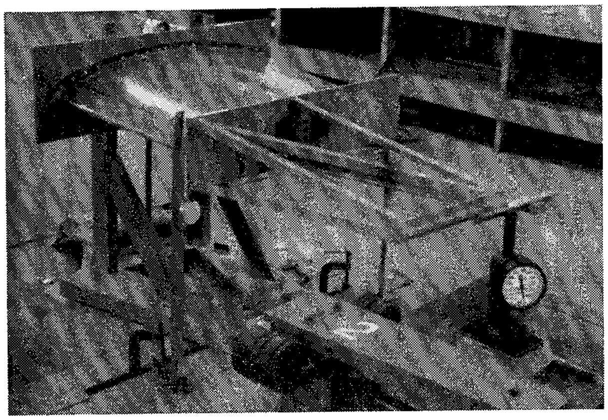

Fig. 5 - Test setup for 30 in. wing

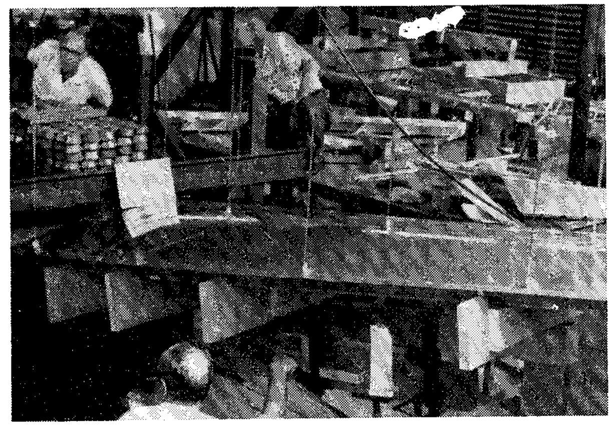

Fig. 7 - Static test setup for positive loads

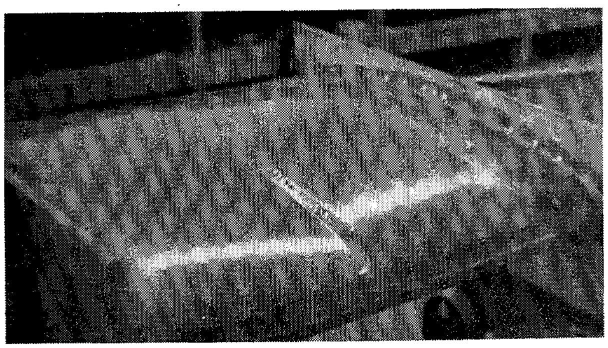

Fig. 6 - Typical failure of 30 in. wing

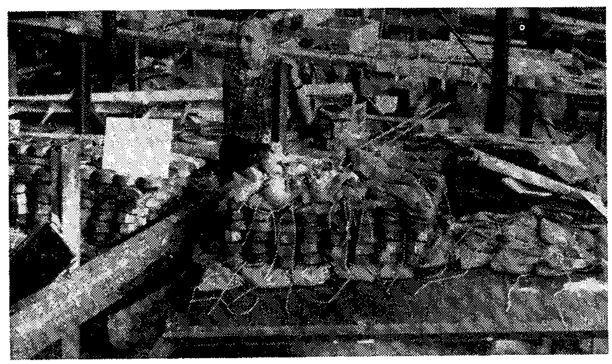

Fig. 8 - Static test setup for inverted loads

It will suffice at this point to say that a suitable high temperature resin from which to build our molds was not available and that during the twelve months we worked on this problem, we consulted with many resin suppliers either in their laboratories or at Vero Beach.

Material Design and Characteristics - Once the 30 in. molds were built, the process details such as lay-up procedures, glue joints, and assembly procedures were worked out by molding a series of parts. These parts were tested and their high structural strength proved (Figs. 5 and 6).

Several available design manuals give good information on the design of reinforced plastic parts. However, any allowable strength data given in any design manual must be used with extreme care. The tensile strength of fiberglas reinforced plastic can vary from 10,000-225,000 psi, depending on the materials and manufacturing process used. No design manual can cover the extremely wide range of all the variables that exist. Therefore the designer must select a process and materials and then make and test samples. We have made and tested hundreds of samples and have not begun to exhaust the possibilities.

Joining Problems - In general, fiberglas reinforced plastics are brittle materials; they have no yield point as such, and the proportional limit is close to the ultimate strength. Thus they have high toughness, or energy to failure, but stress concentrations are more critical than with ductile metals. This is one of the reasons bonded joints are preferred to bolted or riveted joints. This apparent weakness has one happy advantage, however. Fiberglas parts are slightly more notch-sensitive under static loads than under fatigue loading. Therefore a structure that has successfully passed a static test is sure to have a good fatigue life.

Bolted joints are a problem where they are subject to vibration. A bolt under vibration breaks off microscopic particles of glass fiber at the sides of the hole. Since the glass is hard and abrasive and the resin is relatively soft, the vibrating bolt chews its way through the laminate, even at low load levels. To overcome this problem, we embed a plate in the laminate and drill the bolt through it. The metal is hard enough so that the abrasive particles have little effect on it.

Bonding is the preferred way of attaching fiberglas parts to each other. Stress concentrations are reduced, and the resins are natural adhesives. A joint that has peeling loads applied to it, however, must be avoided.

An aircraft structure is a shell that is usually critical in compressive buckling (Fig. 6). The modulus of elasticity of fiberglas reinforced plastic is low, so that conventional construction methods used with sheet aluminum would require an excessive number of stiffeners if made of fiberglas Accordingly, sandwich construction, which has high inherent stiffness, was indicated. The handling characteristics of fiberglas lend themselves well to sandwich construction.

Parts II and III of ANC-23 are design handbooks that are very useful in the design of sandwich structures.

We have chosen paper honeycomb as the core material for our sandwich parts. It has a good strength-to-weight ratio, is inexpensive, and lends itself well to our fabrication processes. The water absorption problems encountered are the same in kind but slightly worse in magnitude than those encountered with aluminum or fiberglas honeycomb.

TESTS

On the basis of the above experience and knowledge we began the detail design and mold construction of the full scale parts for static test and flight test. This phase brought its own set of problems: the handling of large pieces of glass cloth, the positioning and joining of the many pieces of honeycomb required, and the incorporation of the various attachment fittings. All these problems required thought and analysis; also, many required laboratory work for their solution. This work and planning paid off, however; the first parts out of the molds were of satisfactory quality for use in static tests.

The wing was given two static tests: high angle of attack positive loads, and inverted loads on the wing-to-fuselage fittings. Fig. 7 shows the test set up for positive loads. After a series of troubles with the loading structure, the wing failed at 210% of limit load, which is equivalent to 9.25 g. The test was stopped because of a crushing failure of the car caused by insufficient spreading of the load. The fitting test is shown in Fig. 8. This was carried to 200% with no signs of distress.

The fuselage was tested for side bending and torsion due to vertical tail loads and horizontal tail loads. The side load test went to 200% without difficulty. The fuselage failed at 180% on the vertical load test. The failure was a tensile failure through the side of the cockpit area, which started at a bolt hole. This emphasizes the point made above concerning stress concentrations. This load was high enough so that we did not feel it necessary to repeat the test; we simply reinforced that area in the flight fuselage.

The prototype airplane first flew on April 30, 1962. During six months of exposure and 80 hr of flight testing (as of October, 1962), we have had no trouble with the plastic structure. Service and exposure tests are continuing.

CONCLUSION

The greatest progress made during Project PA-29 was in the realm of high temperature plastic molds and production processes. It is noteworthy that in these same areas remains the greatest amount of work yet to be accomplished.

~~As a result of our experience~~ we have concluded that It is not only possible but also quite practical to build primary aircraft structures of fiberglas reinforced plastic. Like any other material it has its own unique set of advantages and disadvantages. Intelligent consideration of these characteristics will allow the designer to present stronger, cheaper, and more appealing products to the flying public.